

The Observed Sensitivity of High Clouds to Surface Temperature Anomalies in the Tropics

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Motivation

- Cloud feedback → for every degree of global warming, how does the TOA radiative impact of clouds change?
 - Largest source of inter-model disagreement
 - Inter-model spread is primarily from low cloud changes
 - LW cloud feedback is robustly positive; not much spread
- Robustly positive LW cloud feedback is due to rise in high clouds
 - Largest single contributor to cloud feedback
 - **Consistent with theoretical expectations**

FAT Hypothesis

Non-Convective
Energy Budget

Horizontal
Convergence

Radiative
Cooling

Subsidence
Warming

T₃

T₂

T₁

σT_c^4



Height →

← Cooling

Heating →

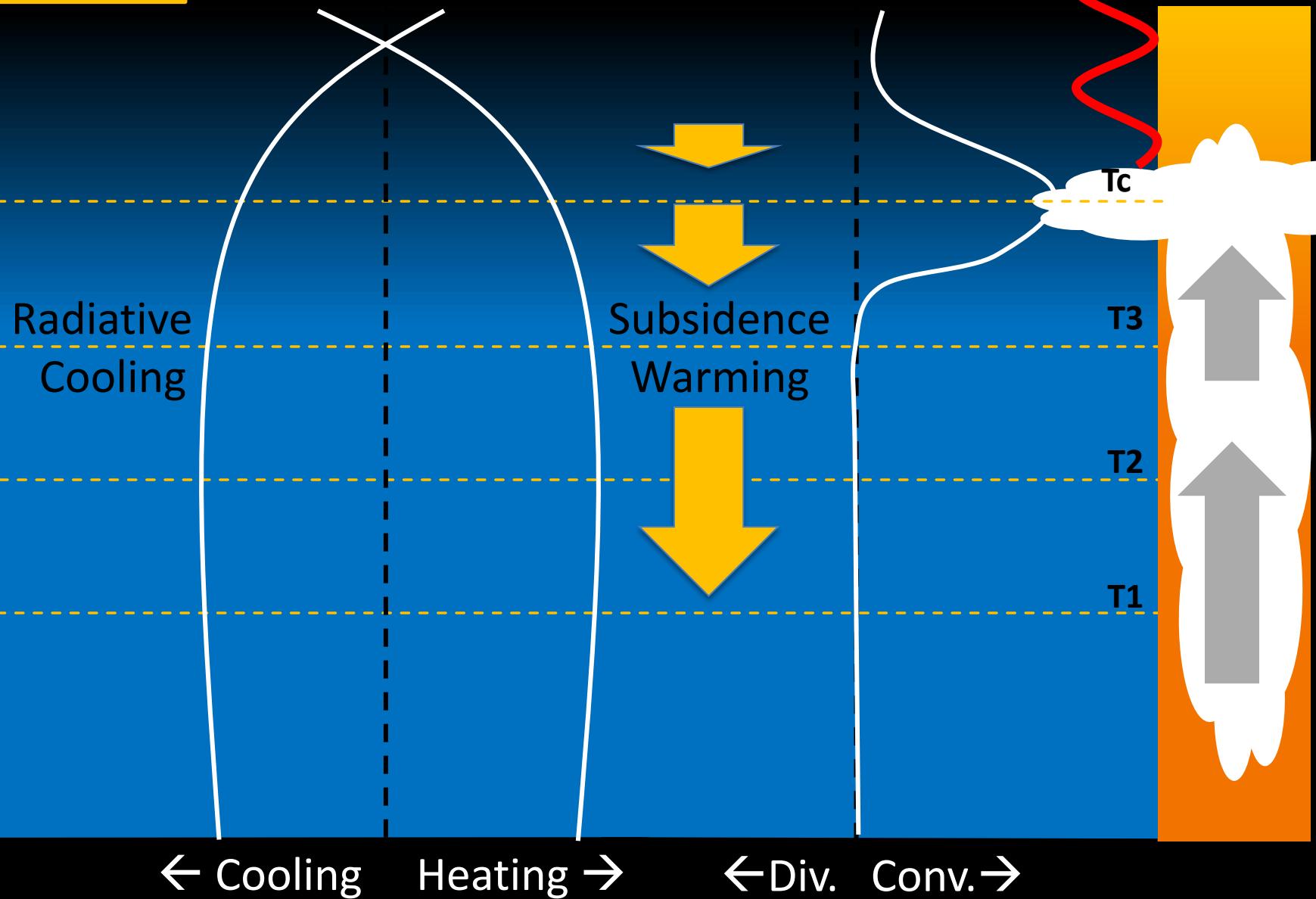
← Div. Conv. →

FAT Hypothesis

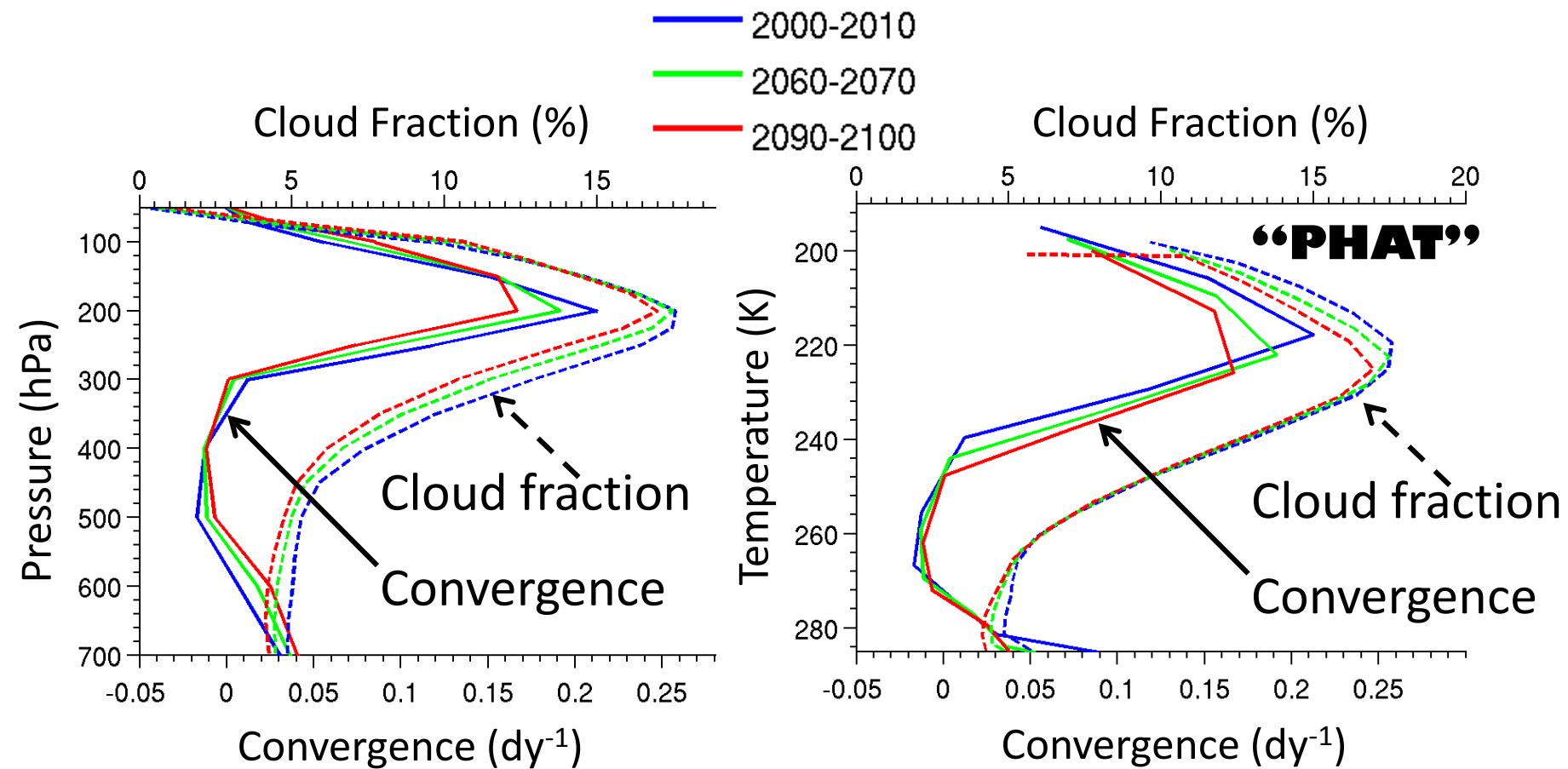
Non-Convective Energy Budget

Horizontal Convergence

$$\sigma T_c^4$$



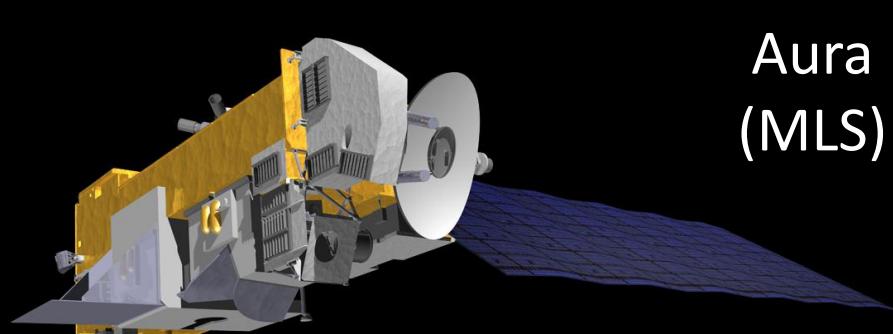
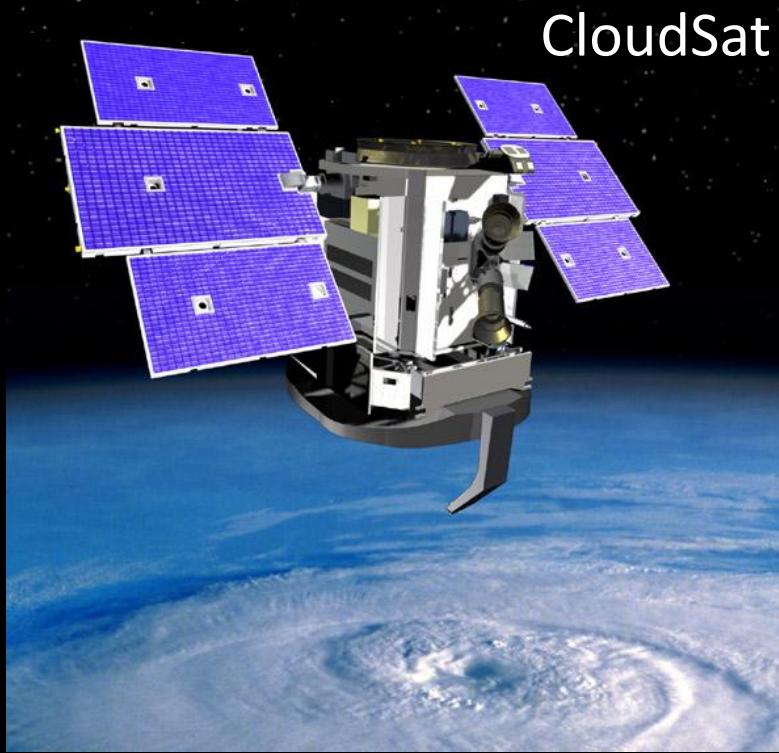
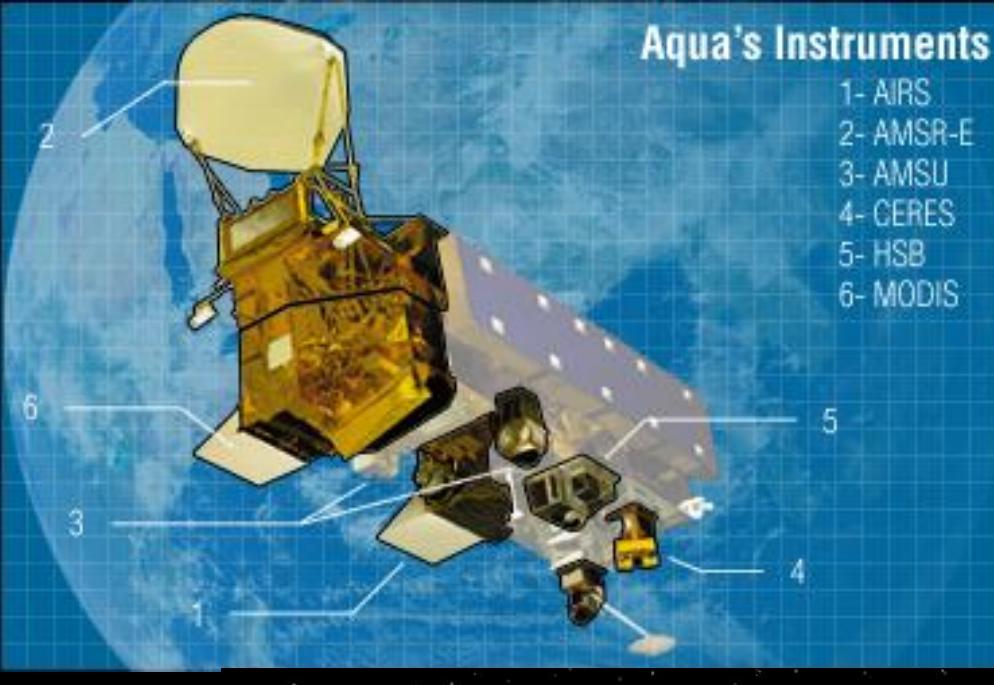
CMIP3 Multi-model mean

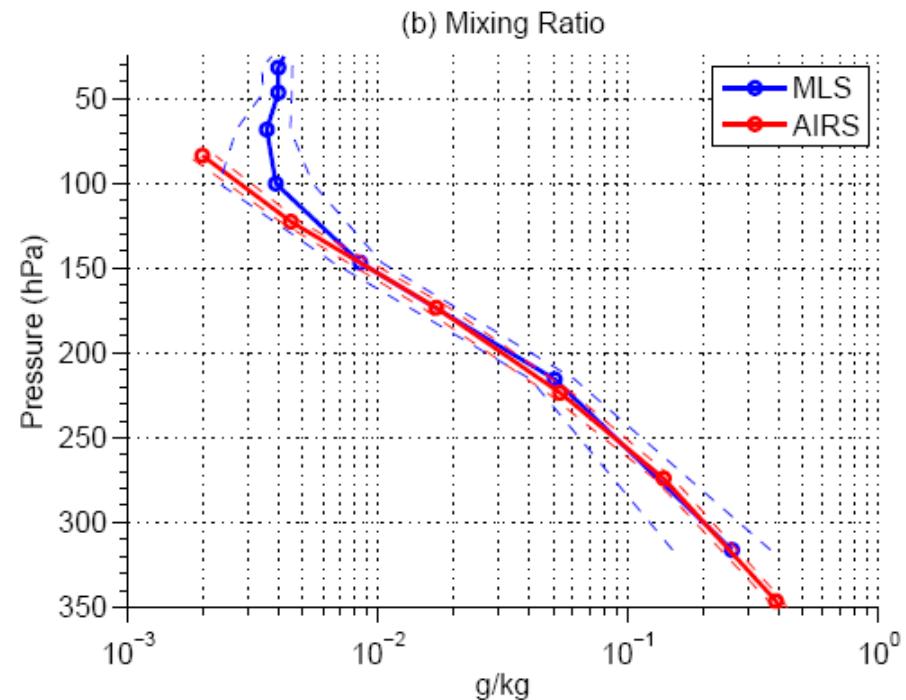
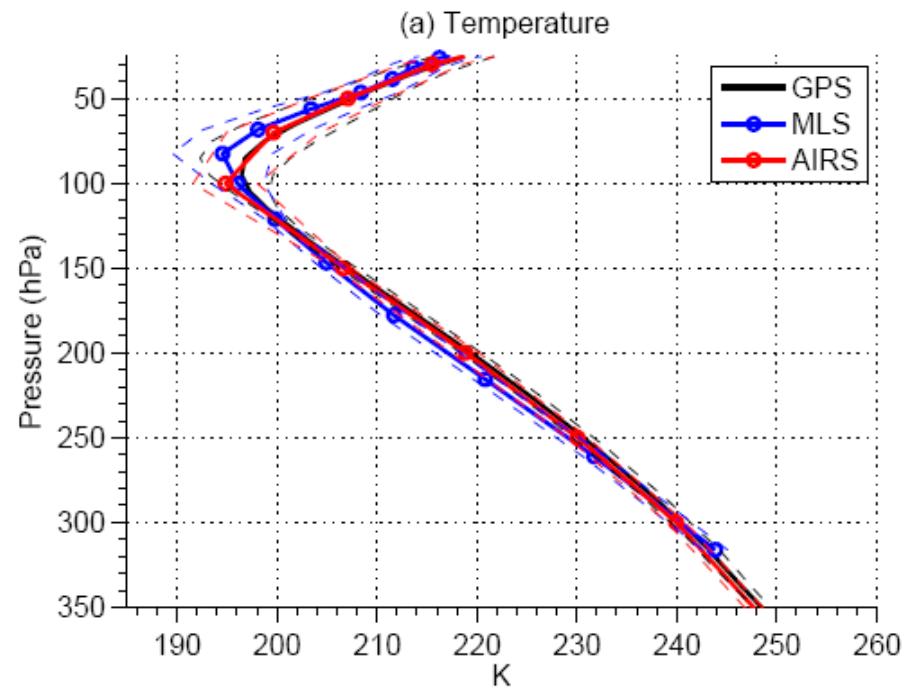


- High clouds rise as the planet warms in GCMs
 - Cause a large, robustly positive LW cloud feedback
 - Well-diagnosed by radiatively-driven divergence

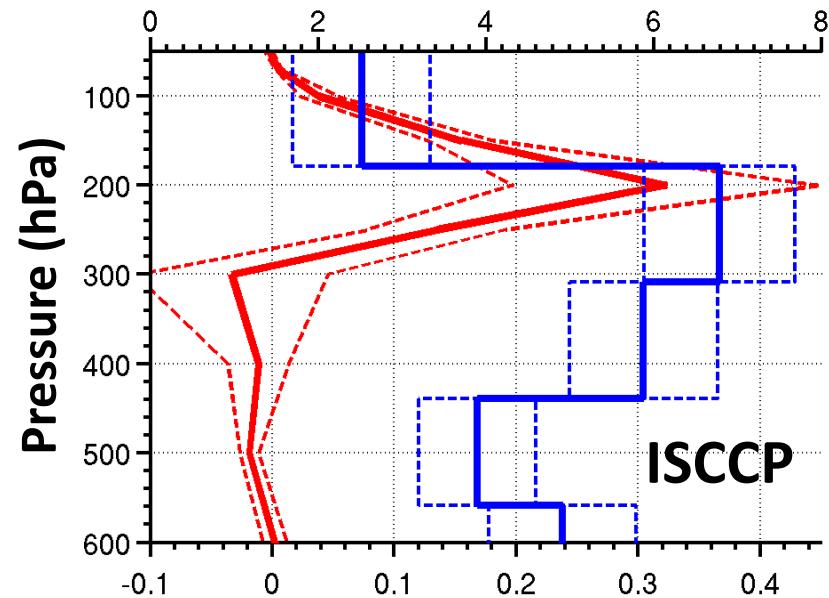
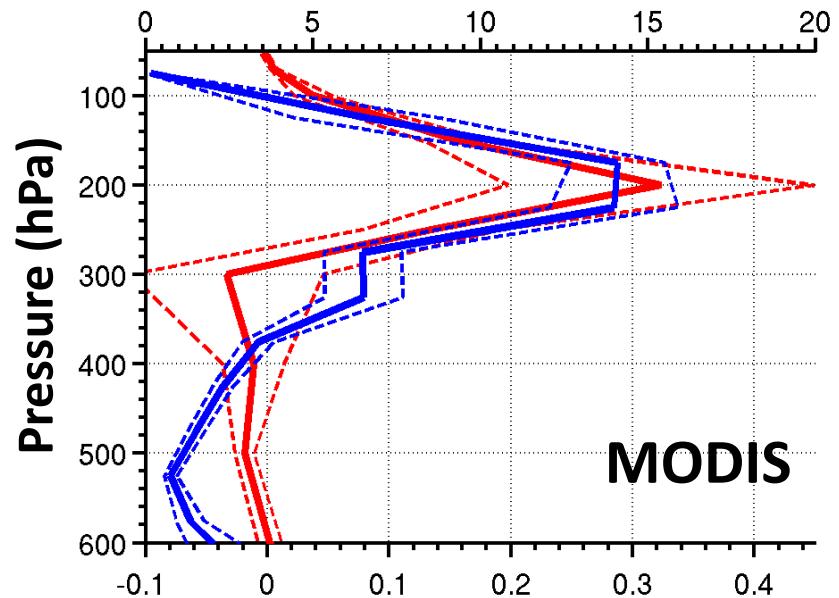
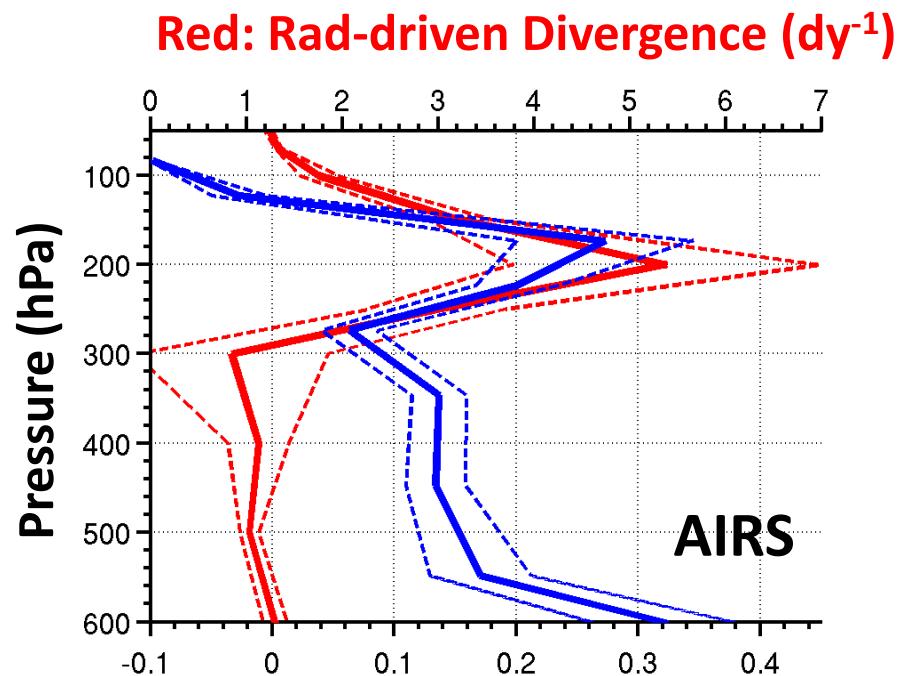
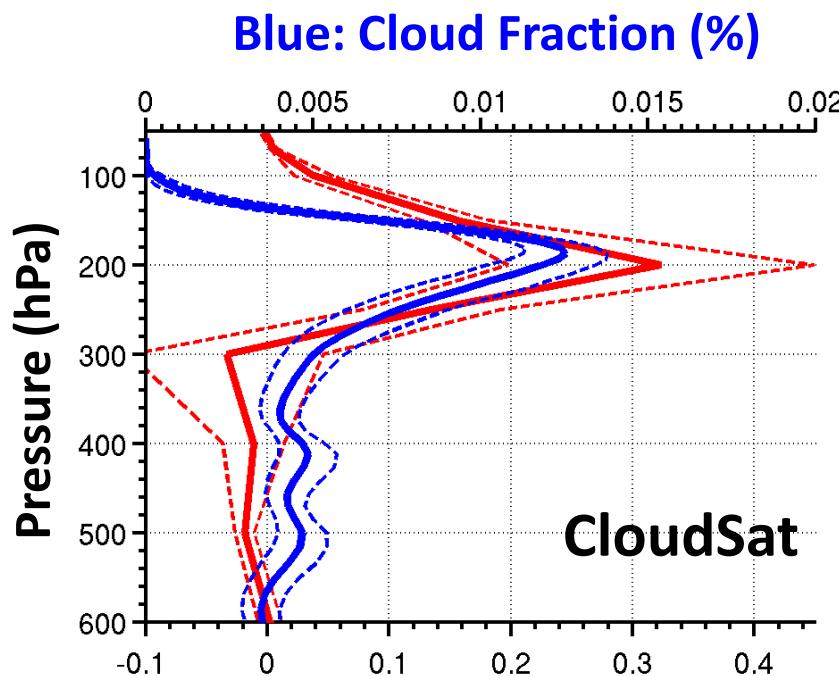
Key Questions

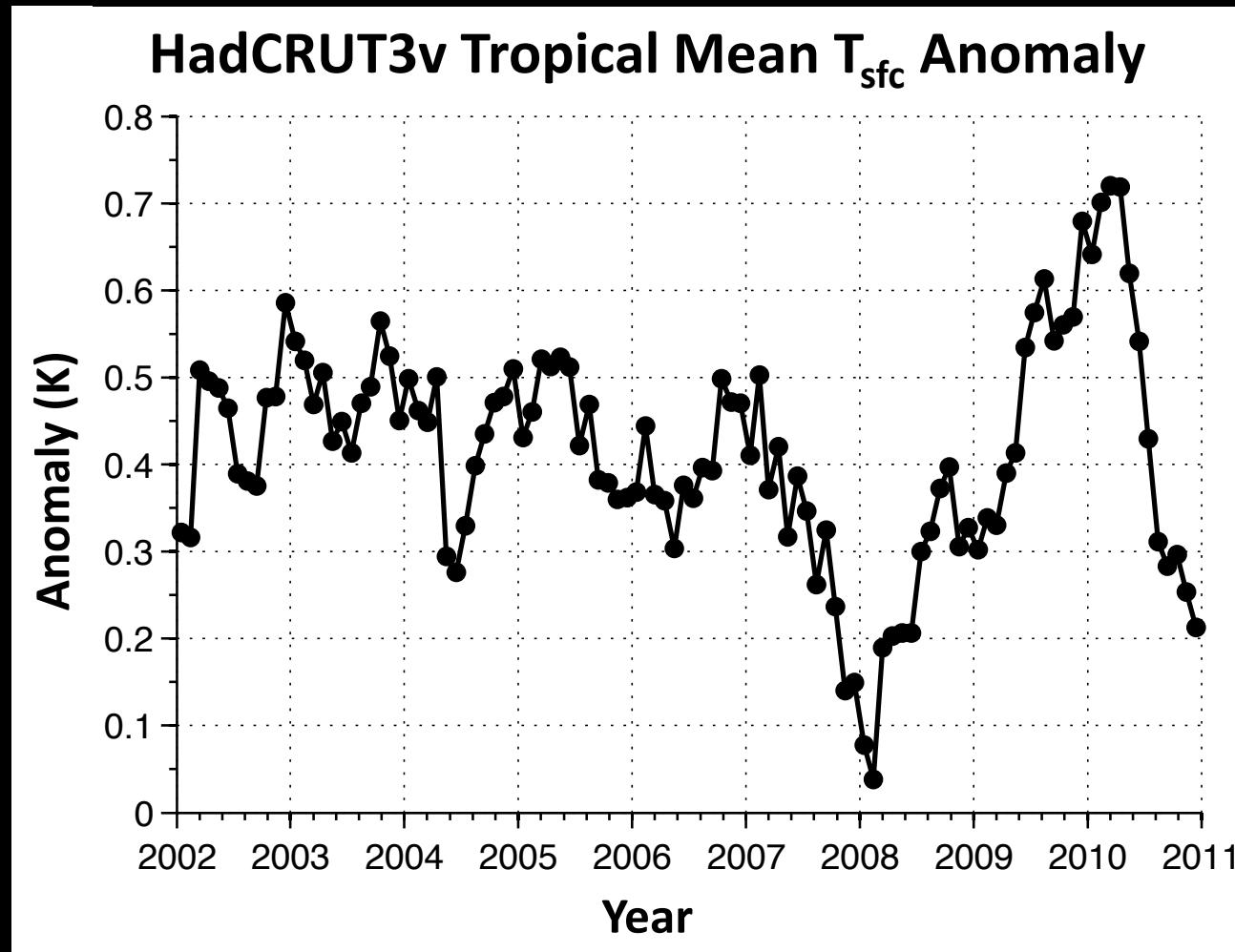
- How do tropical high clouds respond to warming in observations (interannual variability)?
- Is this response consistent with theoretical expectations and with GCM simulations?
- What are the radiative impacts of these cloud anomalies?





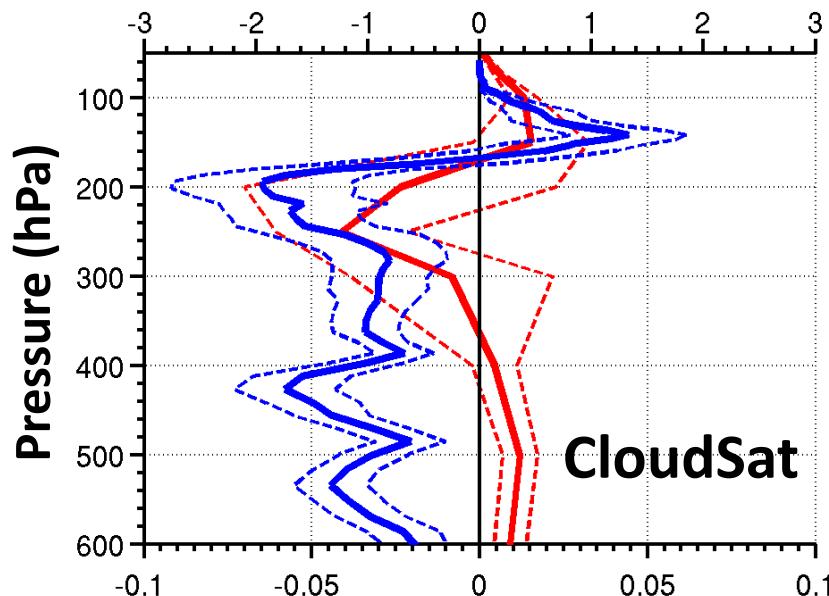
- Create combined AIRS and MLS temperature and humidity profiles
- Send profiles to radiative transfer code → radiative cooling profile
- Assume radiative cooling is balanced by subsidence
- Assume mass conservation → radiatively-driven divergence



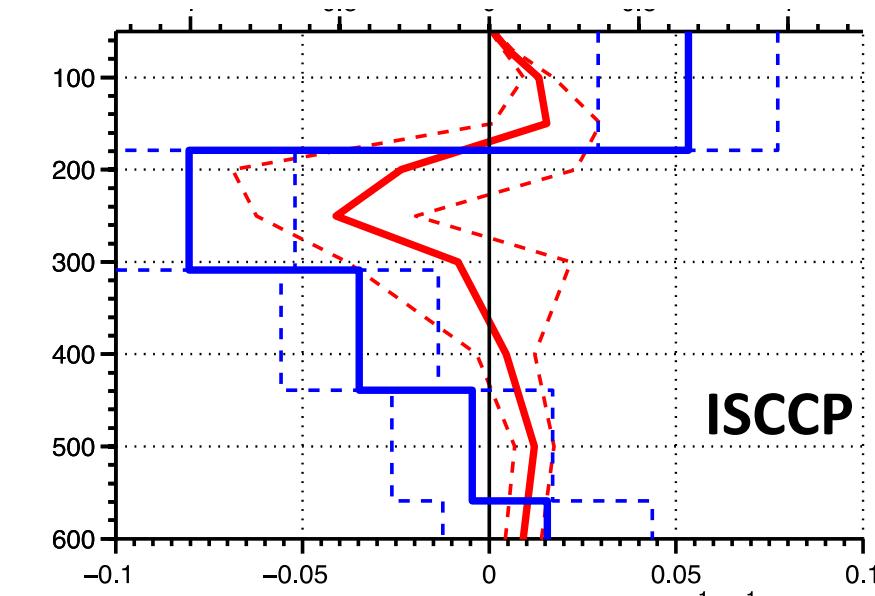
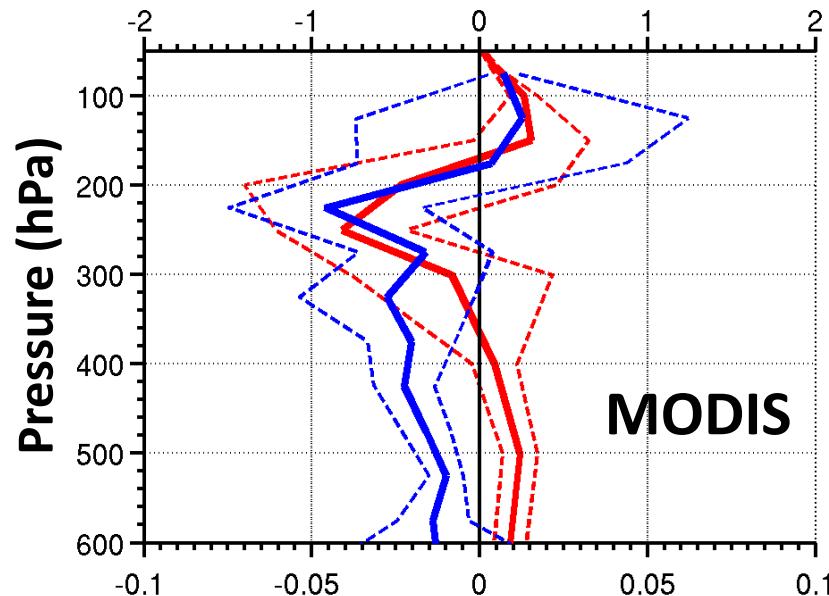
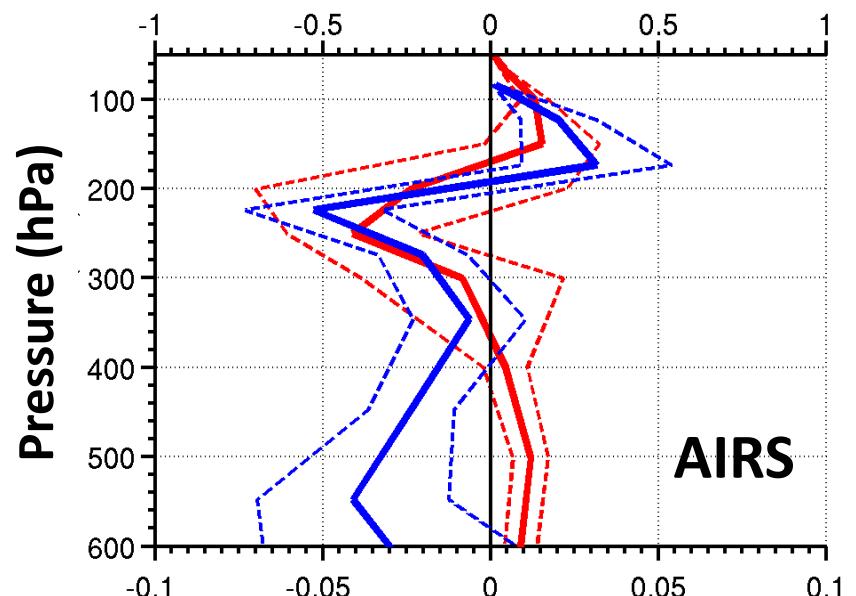


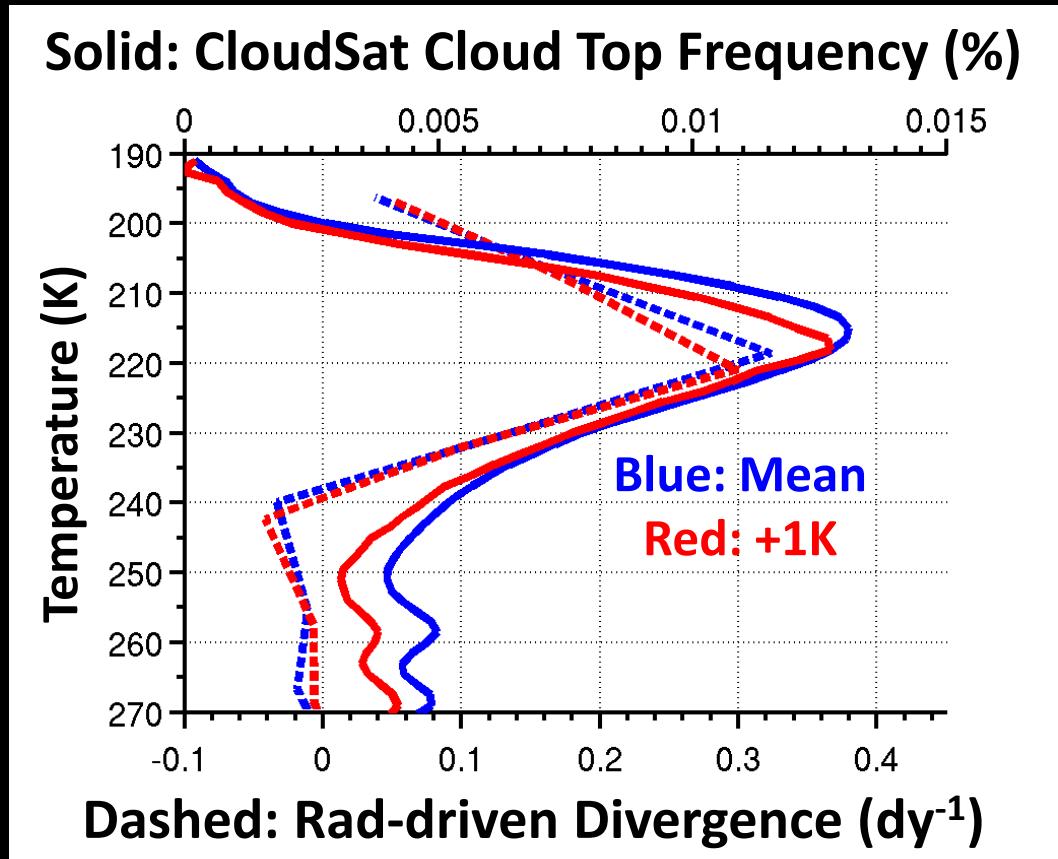
Regress all fields on the tropical mean surface temperature anomalies...

Blue: Cloud Frac. Anom. (% K⁻¹)



Red: Divergence Anom. (dy⁻¹ K⁻¹)



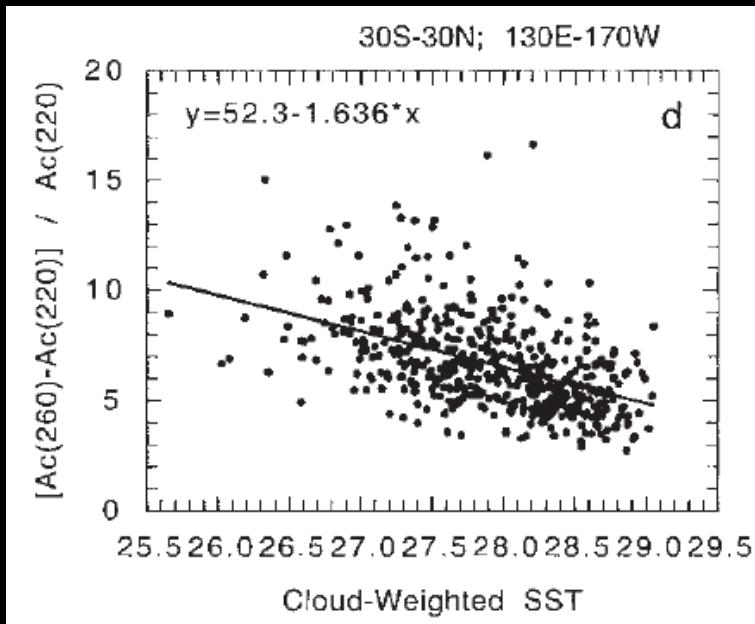


Looks PHAT-like but not statistically different from FAT
-in either case, **high cloud tops rise as Tropics warms**

Does the Earth Have an Adaptive Infrared Iris?



Richard S. Lindzen,* Ming-Dah Chou,+ and Arthur Y. Hou⁺



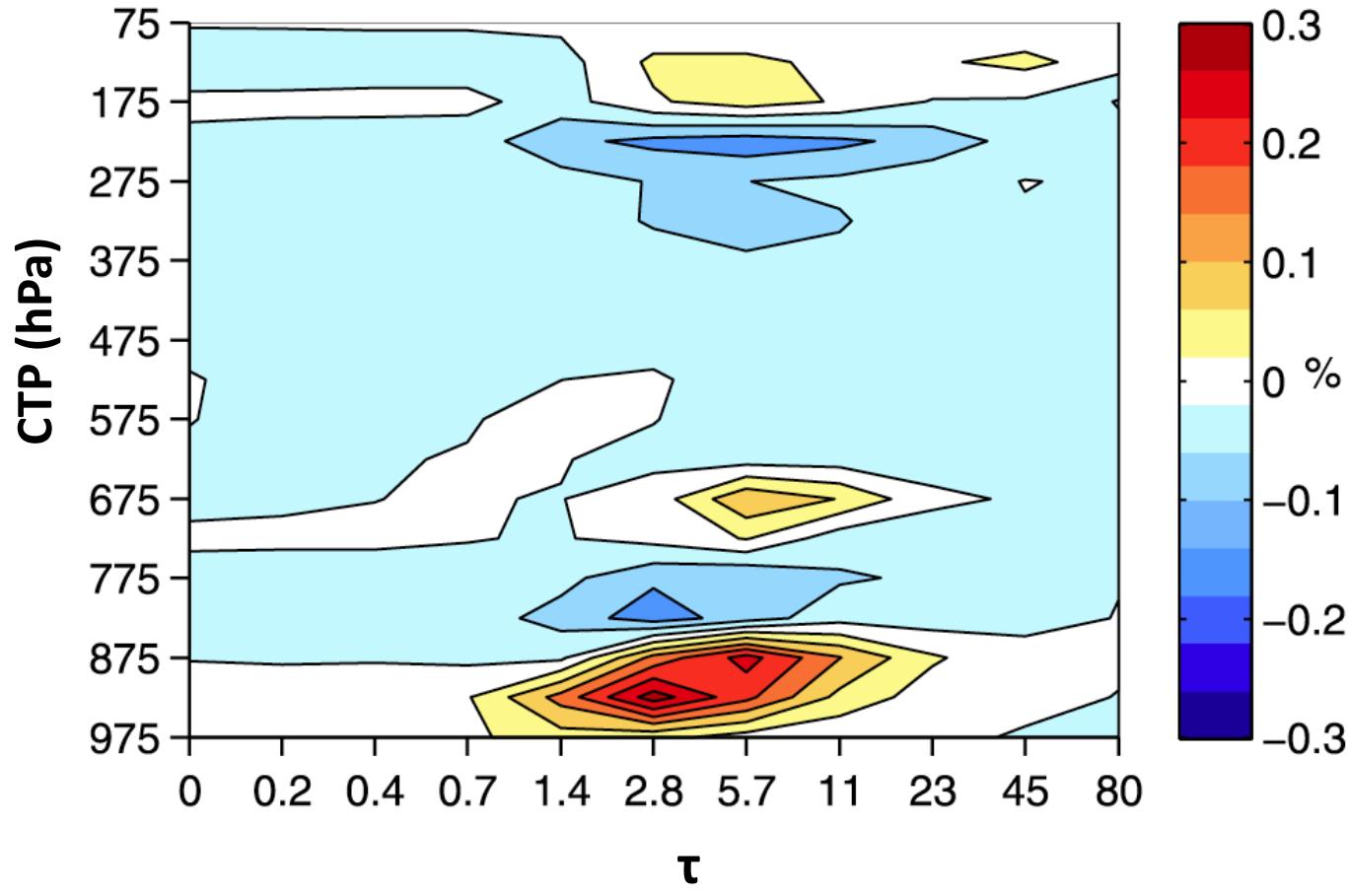
Refuted by:

Harrison (2002), Hartmann and Michelsen (2002 + replies), Fu et al. (2002), Del Genio and Kovari (2002), Lin et al. (2002 + reply), Chambers et al. (2002), Lin et al. (2004 + reply), Rapp et al. (2005), Del Genio et al. (2005), Lin et al. (2006), Wong et al. (2006), Lin et al. (2007), Su et al. (2008)

MODIS Cloud Fraction Anomaly (% K⁻¹)

Total = -0.2±2.2 % K⁻¹

High Only: -1.1±1.1% K⁻¹



Multiply by “cloud radiative kernels” to compute radiative anomalies...

Dataset (Platform)	Temporal Coverage	LW ($\text{W m}^{-2} \text{K}^{-1}$)	SW ($\text{W m}^{-2} \text{K}^{-1}$)
MODIS (Aqua) x Kernel	Sep 2002 – Jul 2010	-1.1 ± 1.6	0.7 ± 2.7
MODIS (Aqua) x Kernel [High Clouds Only]	Sep 2002 – Jul 2010	-1.0 ± 1.4	1.3 ± 1.3
ISCCP x Kernel	Jul 1983 – Jun 2008	-0.3 ± 0.4	0.7 ± 1.3
ISCCP x Kernel [High Clouds Only]	Jul 1983 – Jun 2008	-0.2 ± 0.4	0.5 ± 0.4

Suggests that **SW “iris”** dominates over **LW “iris”**
 → consistent with Lin et al. (2002), The iris hypothesis: A negative or positive cloud feedback?, *J. Clim.*, **15**, 3-7.

Dataset (Platform)	Temporal Coverage	LW (W m⁻² K⁻¹)	SW (W m⁻² K⁻¹)
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CERES SSF (Terra)	Mar 2000 – Dec 2010	-0.4 ± 1.0	0.8 ± 1.1
CERES SSF (Aqua)	Jul 2002 – Dec 2010	-0.8 ± 1.1	1.3 ± 1.2
CERES SYN (Terra)	Mar 2000 – Dec 2010	-0.7 ± 1.0	1.1 ± 1.1
CERES SYN (Aqua)	Jul 2002 – Dec 2010	-0.5 ± 1.2	0.6 ± 1.3
CERES EBAF (Aqua & Terra)	Mar 2000 – Dec 2010	-0.7 ± 1.0	0.7 ± 1.0

|LW “iris”| < |SW “iris”|

Key Questions

- How do tropical high clouds respond to warming in observations (interannual variability)?
 - Clouds **rise** but exhibit a **decrease in coverage**
 - Cloud changes **suggestive of PHAT**, but can't rule out FAT
- Is this response consistent with theoretical expectations and with GCM simulations?
 - Yes! Radiatively-driven divergence **closely tracks** observed cloud profiles, just as it does in GCMs
- What are the radiative impacts of these cloud anomalies?
 - Reduction in high cloud coverage results in a **net heating** of the Tropics because enhanced downwelling SW exceeds enhanced upwelling LW, like a **reverse-iris** effect

Thank you!

Zelinka, M.D. and D.L. Hartmann, 2011: The Observed Sensitivity of High Clouds to Mean Surface Temperature Anomalies in the Tropics. *J. Geophys. Res.*, **116**, D23103.